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F1N
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(54) Utilising wave energy

(57) One or more vertically disposed resilient bellows 2 have one end attached to a float 1 which follows the liquid wave movements and the opposite end attached to a plate 3 located some distance below the liquid surface, which has a high hydraulic impedance. Each bellows has inlet and outlet non-return valves 5, 6 so that pumping of the liquid occurs due to expansion and contraction of the bellows as the float moves up and down relative to the plate.

FIG.1

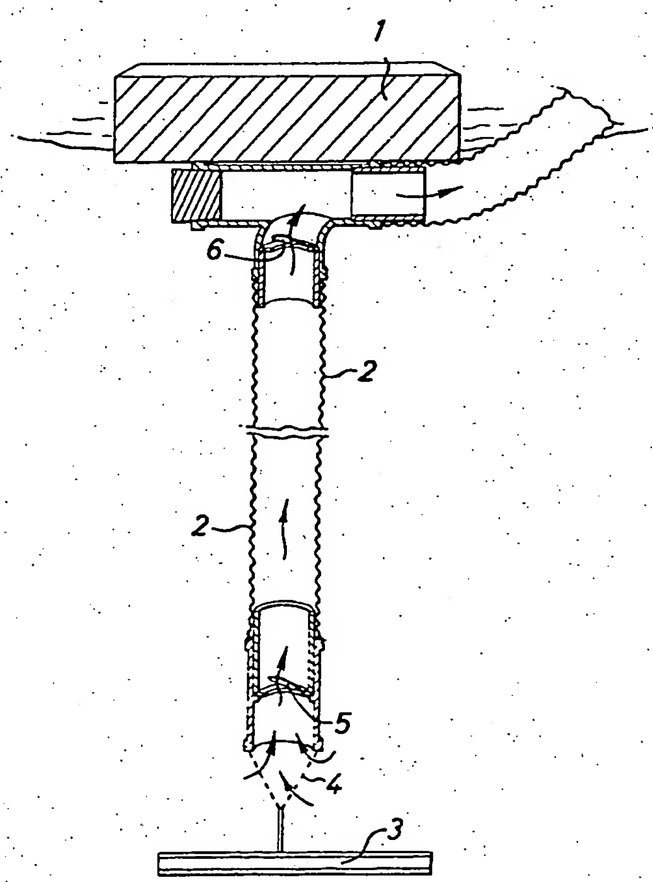

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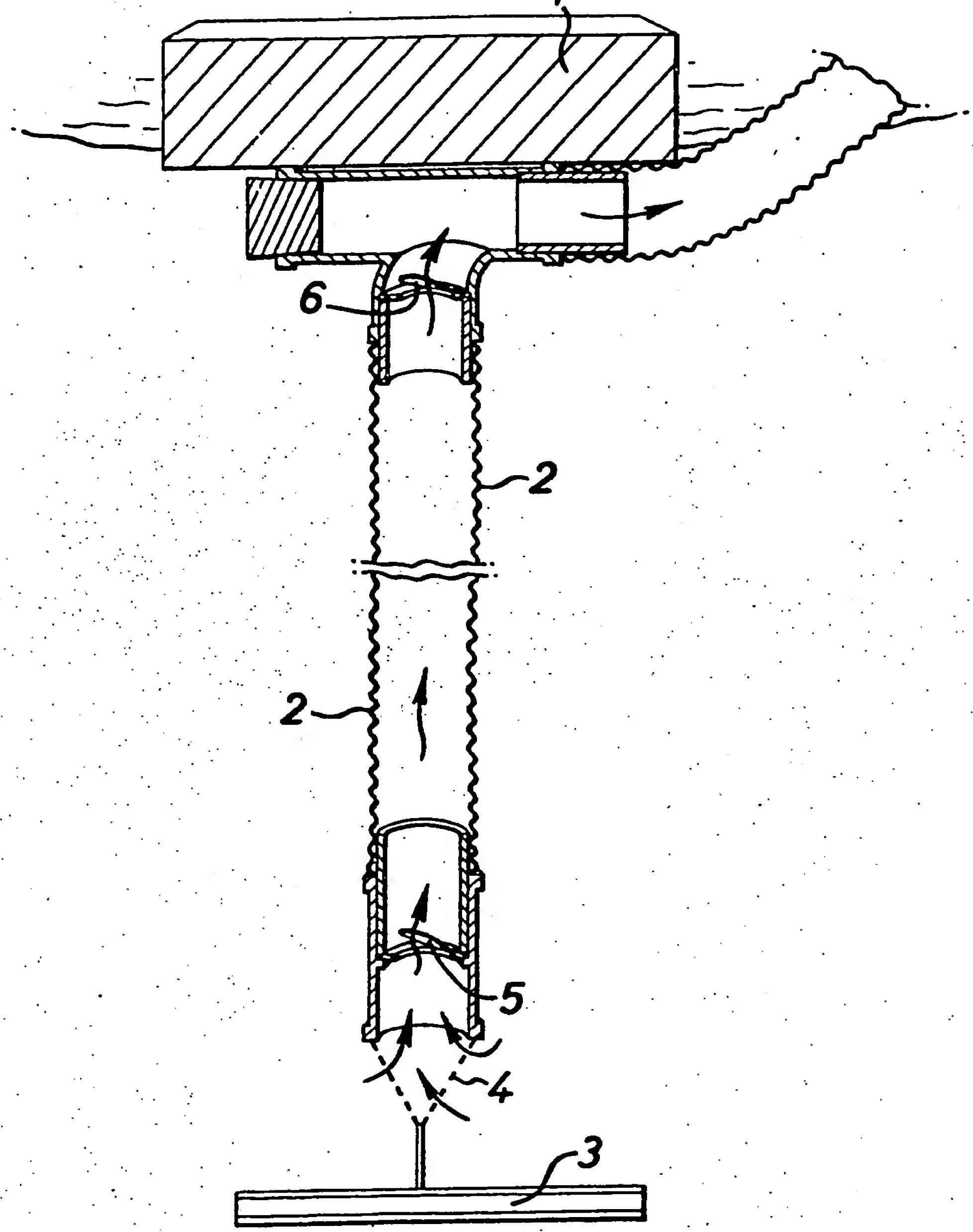
FIG.1



Formal Drawings.
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FIG. 2

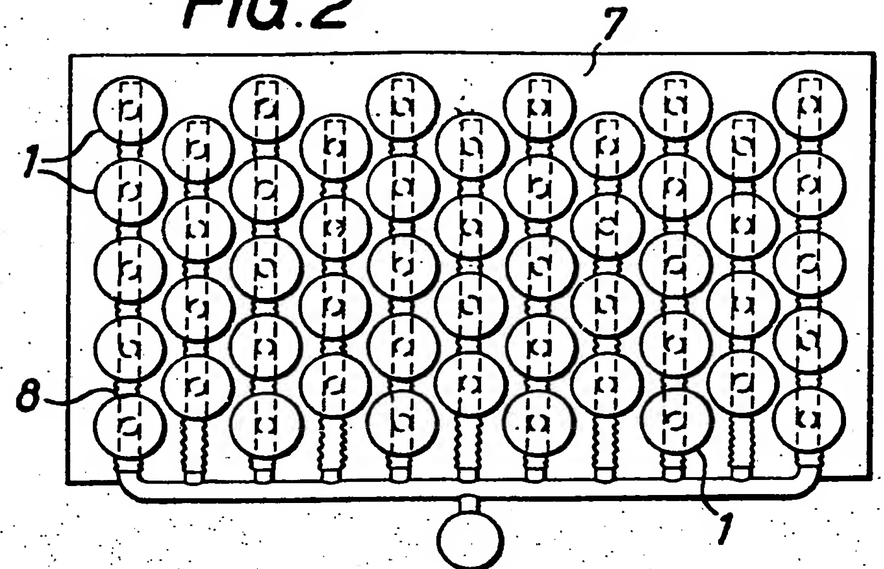
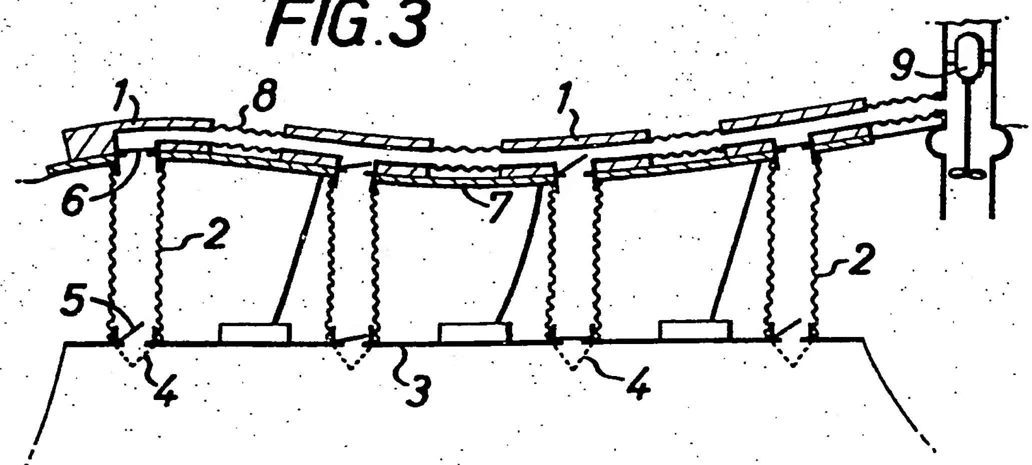


FIG. 3



Formal Drawings.
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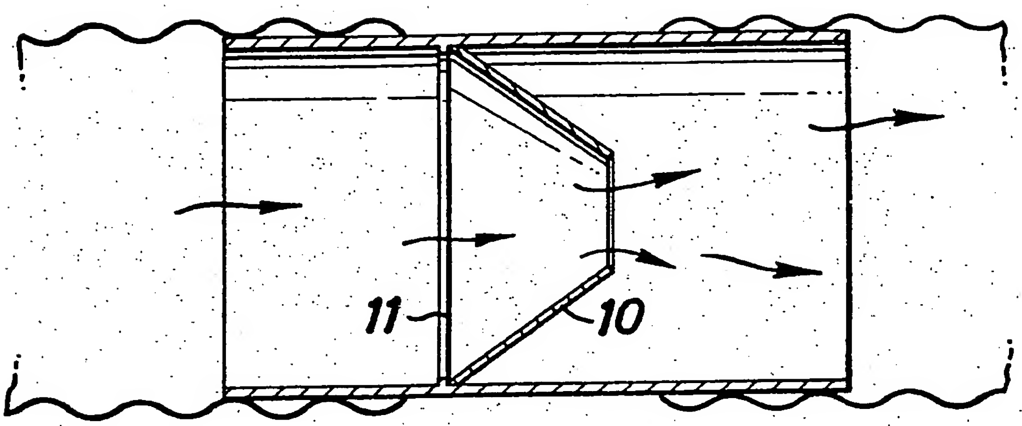

FIG.4

Formal Drawings.
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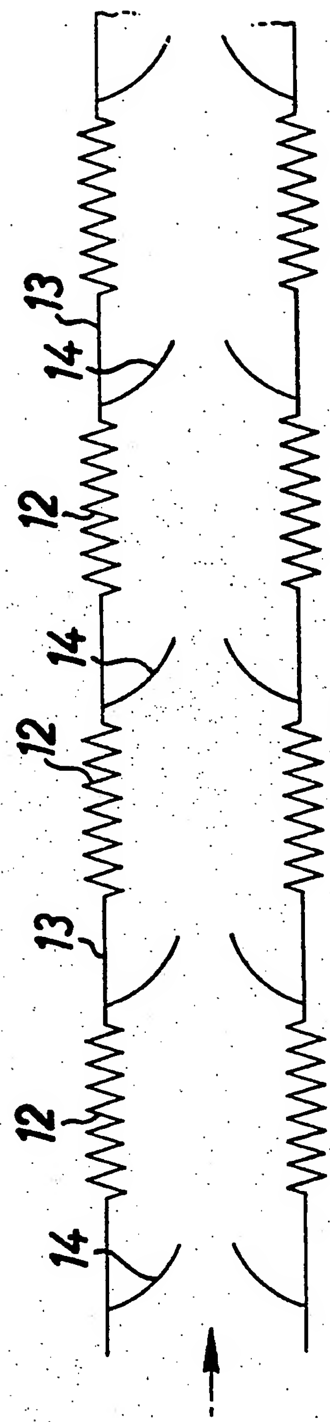

FIG.5

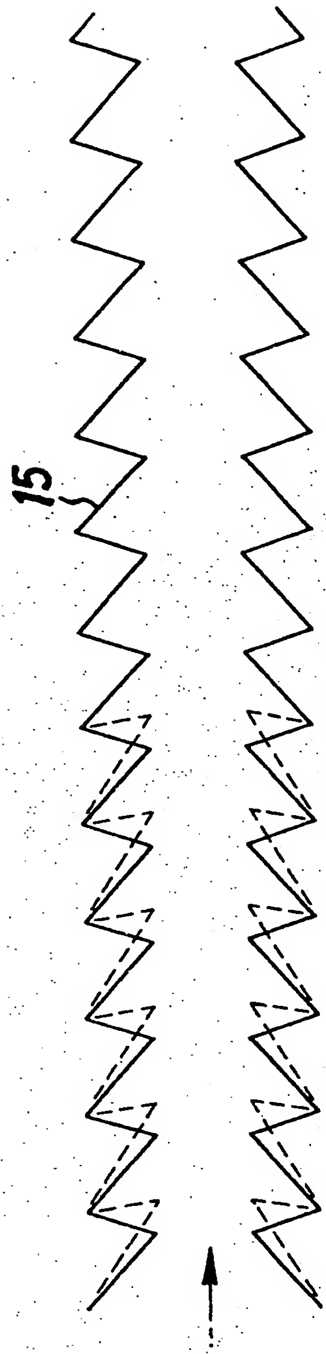

FIG.6

SPECIFICATION
Wave energy device

This invention relates to energy conversion and more particularly to the conversion of energy from the movement of waves of a liquid.

Wave motion has long been regarded as a potential source for power generation and a number of suggestions have been proposed for the extraction of this power, for example, our co-pending U.K. patent application No. 30142/76 (4165).

Thus according to the present invention there is provided a device actuated by wave motion comprising one or more liquid wave actuated pumps, each pump comprising a surface float or raft which partially conforms to the changes in liquid surface level during the passage of waves, a resilient tube suspended from the float, which tube is capable of changing volume when extended or contracted, and having inlet and outlet unidirectional valves and a means to maintain the lower end of the tube at a substantially constant level below the surface of the liquid.

In use of the device, relative motion of the surface float or raft and the lower end of the tube causes liquid to be pumped into the tube through an inlet valve when the tube volume increase and through an outlet valve when the tube volume decreases. The resultant water flow may, then for example, be passed into a turbine or the like to produce electricity.

Where the capacity of one pump is insufficient a plurality of pumps may be arranged in an array to pump more liquid. In an array of pumps it is preferable to link each pump module with a flexible floating matrix at the surface and a matrix of density greater than the surrounding fluid below the surface.

An array of pumps may extend as a line across the surface of the fluid or as a raft in both dimensions across the surface. Where the pump units are arranged in a line each may be subjected to similar wave conditions. In a two dimensional surface raft at right angles to the wave front the pumps nearest to the approaching waves will be subjected to the full wave action while those further from this edge will be subjected to progressively attenuated waves. An array of pumps may be connected by a system of manifolds to collect the water pumped from the outlet valves. In normal wind driven sea waves the intermittent water flow from each unit of any array of pumps will be added in the manifold system to provide a more steady flow at the manifold outlet.

When extended from its normal free length, the tubing may exert a restoring force to regain its original length. Also the wave energy device may be operated with tubing which exerts a restoring force when compressed. The changes in length of the tube caused by wave motion result in a change in the enclosed volume of the tube as in a concertina. Preferably the change in volume of the resilient tube causes unidirectional liquid flow by drawing liquid through the inlet non return valve system while the volume of the tube increases and expelling the liquid through a second non return valve system into, for example, a manifold while the volume decreases.

Supplementary valves may be used between the inlet and outlet valves if desired for example, to minimise back flow. The tube must have sufficient structural strength to maintain the changes in its volume caused by the waves while subjected to the fluctuating pressures associated with the pumping of the fluid. The tubing may be in the form of a flexible duct e.g., a bellows vacuum cleaner hose, in which the required restoring force during extension and/or compression is provided by a helical spring which is enclosed by, embedded in or overlaid with a flexible covering sheet, e.g., plasticised polyvinyl chloride, synthetic and natural rubbers. The springs may be of corrosion resistant material, e.g., stainless steel, or encased in a protecting pocket in the outer covering sheet.

In an alternative form of the unidirectional valves a continuous bellows section has one or more conical projections and preferably the diameter of each conical projection tapers in the direction of travel of the liquid waves along the device.

In another alternative form, the interior wall of the floating tube is contoured so as to present a low resistance to liquid flow in one direction and a high resistance to reverse flow. One or more flow control sections thus cause uni-directional pumping of liquid. This uni-directional liquid flow may then be used directly for mechanical work or to generate electricity.

In yet another alternative form, the flow control portion of the floating tube is formed from an essentially rigid material whereas the joining portions are formed of a flexible material whereby the flexing causes uni-directional liquid flow along the floating tube.

If the device is operated in shallow water, i.e., the wavelength of the longest waves in which the device is required to operate is greater than twice the water depth, it is preferable to attach the lower end of the pump tube to an anchoring system on the sea bed to provide the vertical restraint to the buoyancy forces. In deeper water the anchoring system is preferably a plate of mesh which is suspended from the pumping tube sufficiently far below the surface to be largely unaffected by surface waves. The plate or mesh has a large hydraulic impedance to provide a restraint against the surface buoyancy and has sufficient weight to return the plate to its position in still water against the upward forces exerted by the pump tube when operating in waves. When the pumps are connected in an array by a flexible matrix at the surface to make a raft, the subsurface plates or meshes of each pump are preferably connected by a similar matrix.

The surface and subsurface matrix material may be in the form of netting of natural fibre or plastic

rope, or mesh or matting of plastic wood or metal.

The subsurface plate or mesh (reaction plate) is preferably fitted with inflatable chambers which may be filled with air during launching and towing to the site of operation to reduce the draught of the system. Subsequent flooding of the chambers allows the subsurface plate to sink to the desired operating level.

The structure is provided with suitable means for towing and positioning, e.g. cables and ropes, and also for anchorage purposes. Anchoring may be made by use of ropes or wires, e.g. nylon or chains to a buoy or directly to sea bed anchors.

The construction of the device is determined by the operating wave conditions and the type of fluid flow required. Preferably the sub-surface plate should be sufficiently heavy to cause the buoyancy units to be almost half submerged in still water.

Preferably the surface floats should have sufficient excess buoyancy above that required to float in still water so that they just remain at the surface during the passage of the maximum wave crest anticipated while extending the pumping tube by about half the height of the wave. The restoring force of the tube when returning to its normal contracted length then determines the maximum pressure pumped by each unit. For a given set of wave conditions the tubes may be chosen to pump a small volume at relatively high pressure or high volume at low pressure or some intermediate combination.

The devices may be used for various water pumping operations, e.g. for inflation of wave calming booms or pumping sea water for trace element extraction plants.

The device may be used to pump the fluid in which the waves occur or, by the provision of manifolds to both the inlet and the outlet valves, to pump a different liquid or air in a closed circuit.

For sea water operation the materials of construction should be resistant to corrosion and marine fouling.

The invention will now be described by way of example with reference to the accompanying drawings.

Figure 1 shows a vertical section through a wave energy device comprising a single vertical tube pump module.

Figures 2 and 3 show plan and vertical sections of a multi module device employing vertical pumps.

Figures 4, 5 and 6 illustrate various embodiments of the flexible tubes.

In Figure 1, a surface float of foam plastic 1 supports a steel spiral wound plastic coated bellows tube 2 to which the subsurface plate 3 is attached. When a wave crest causes the float to rise, the subsurface plate, which is in still water, resists the upward motion causing the bellows to extend. The resultant increase in volume is accompanied by the flow of water through a coarse filter 4 and a non return inlet rubber flap valve 5. As the crest passes and a trough approaches, the restoring force in the extended bellows causes contraction and expulsion of water through the outlet valve 6.

Figures 2 and 3 show a multiple pump wave power array. A series of pumps may be used together to pump large quantities of sea water for electricity generation. A number of surface floats 1 comprising blocks of foamed plastics material are located on a surface mesh 7 and the buoyancy produced is substantially in excess of that required merely to cause flotation.

A manifold pipe 8, open at one end, is attached to the float 1 and a number of tubes 2 are connected to the manifold pipe 8 and pass vertically to a subsurface mesh plate 3. The tubes 2 take the form of a concertina or bellows tending to recover its shape when compressed or extended.

Each vertical tube 2 has a one way valve 6 at each end. The valve at the subsurface mesh plate 3 end of the tube 2 only admits liquid into the tube 2 whereas the valve at the raft end of the tube 2 only allows liquid to pass from the tube 2 into the manifold pipe 8. The valve 5 simply comprises a flap of rubber which is attached to a pivot point at the end of the tube.

For use in sea water, it is desirable to place a filter 4 at the inlet to the tubes 2 so as to reduce the possibility of valve blockage.

In use of the device, an incident liquid wave causes the float 1 to move in sympathy. The subsurface mesh plate 3, because of its inherent inertia, remains at substantially the same liquid height and thus the relative movement between the raft 1 and the anchoring plate 3 causes alternate compression and extension of tubes 2 as the incident wave passes. Thus when a particular float 1 rises when a wave crest approaches, the associated inlet flap valve 5 opens as water is drawn through the filter 4 into the tube 2. When the float 1 falls with an approaching wave through the restoring force of the extended tube 2 forces water out of the outlet valve 6 into the manifold 8. The manifold, which is itself flexible, collects water from all the pump units and passes it to a turbine unit 9 which floats in the protected water at the back of the array away from the incident waves. The turbine 9 then discharges the water back into the sea. Water flow is the result of many pumps all operating out of phase and storing water in the turbine tube.

The array may be moored from the subsurface plate 3 to conventional anchors or concrete lumps.

Tests on models of the pump system were carried out in a 16 × 3.6 × 1.2 m wave tank. The single pump unit consisted of a buoyancy cell 1 of dimensions 150 × 205 × 50 mm with a length of 35 mm diameter domestic vacuum cleaner suction hose 2 suspended vertically below it. This was attached to the buoyancy 1 by means of a $1\frac{1}{4}''$ diameter swept tee, pipe fittings as shown in Figure 1. The tube

length was 220 mm (compressed) and 600 mm (freely suspended in water).

Non return valves 6 constructed from $1\frac{1}{4}''$ diameter stainless steel washers and nylon reinforced polychloroprene were located at each end of the tubing 2 so that the flow direction within the tubing was vertically upwards, towards the buoyancy. The characteristics of the pump tube 2 were varied by changing the anchored level of the lower end of the tube using an idealised system of a clamp fixed to the tank. Results are shown in tabulated form in Table 1. The flow rate of a single pump module operating in a range of wave conditions was measured for a series of working extensions (the pump tube length when the lower end was clamped and the surface float was in still water). This flow rate was determined with the outlet tube 220 mm above the static water level, i.e., a working pressure of about 0.3 p.s.i.g. The results showed that the unit had an optimum working extension between 700 and 730 mm. Above and below which the flow rate decreased.

TABLE 1 — Flow Rates

Buoyancy Dimension 205 × 150 × 50 mm						
Waves Incident on 150 mm Buoyancy Dimension						
Wave Length λ	Amplitude mm	Working Extension (mm)				
		670	700	730	760	820
1	36	515	1325	850	720	358
	47	1530	2095	2000	1910	1446
	65	2667	2720	3429	3160	2667
2	30	490	653	603	643	400
	40	1080	1167	1287	1267	1000
	53	1570	1850	2150	2069	1670
3	30	150	350	240	293	190
	41	510	640	600	570	510
	52	1143	1330	1227	1240	1180

Figures 4, 5 and 6 illustrate various embodiments of the flexible tubes.

Figure 4 shows a flexible continuous tube having the corrugated form of a bellows or concertina. Projecting cones or other suitable shapes are attached to the interior walls of the bellows or concertina. Suitable projecting cones are funnels 10 having the stems cut off, the mouth of the funnels being attached continuously around the interior 11 of the bellows or concertina to form a series of valves.

Figure 5 shows a modified form of tube as which alternate flexible corrugated sections 12 and stiff sections 13. The stiff sections 13 have the flow control units or projections 14 attached to them.

Figure 6 shows a further form of tube having integral flow control units or projections 15. During flexing of the tube, the positions of the projections 15 change (as indicated by the dotted lines). The contouring of the interior of the tube allows opposite pairs of projections to act as semi one-way valves and cause uni-directional pumping of water in the tube.

CLAIMS

1. A device comprising one or more liquid wave actuated pumps, each pump comprising a surface float or raft which partially conforms to the changes in liquid surface level during the passage of waves, a resilient tube suspended from the float or raft, which tube is capable of changing volume when extended or contracted, and having inlet and outlet uni-directional valves and a means to maintain the lower end of the tube at a substantially constant level below the surface of the liquid.

2. A device according to claim 1 in which the resilient tube is a flexible duct in which a helical spring is enclosed by embedded in or overlaid with a flexible covering.

3. A device according to claim 2 in which the flexible covering in plasticised polyvinyl chloride, synthetic rubber or natural rubber.

4. A device according to claim 2 in which the spring is fabricated from a corrosion resistant metal.

5. A device according to claim 2 in which the spring is enclosed in a protecting pocket.

6. A device according to claim 1 in which the resilient tube is a spring loaded bellows.

7. A device according to claim 1 in which at least one of the uni-directional valves is a non-return valve.

8. A device according to claim 1 in which the uni-directional valves comprise a continuous bellows section having one or more conical projections, the diameter of each conical projection tapering in the direction of liquid wave flow along the device.

9. A device according to claim 1 in which the interior wall of the resilient tube is contoured so as to present a low resistance to liquid flow in one direction and high resistance to liquid flow in the reverse direction.

10. A device according to claim 1 in which the resilient tube comprises rigid tube portions having conical projections tapering in the direction of liquid wave travel joined by resilient tube portions.

11. A device according to claim 1 in which the maintaining means is a plate or mesh having a large hydraulic impedance to vertical movement caused by liquid waves acting on the surface float or raft.

12. A device according to claim 11 in which the plate or mesh is fitted with inflatable chambers which are capable of being filled with air during launching and towing to the operational site, the chamber then being flooded until the plate or mesh sinks to the desired operating level.

13. A device according to claim 1 in which the surface float or raft comprises a mesh or matting having inherent or attached buoyancy.

14. A device according to claim 1 in which the mesh or matting is fabricated from wood or plastics material.

15. A device according to any of the preceding claims in which the liquid pumped is used to drive energy generating equipment directly or indirectly.

16. A pumping device as hereinbefore described with reference to Figures 1 to 6 of the accompanying drawings.

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